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ABSTRACT

The Special Intensive Program for Scientists and Engineers (SIPSE) at Diablo Valley College in California replaces the traditional engineering calculus and physics sequences with a single sequence that combines the two subjects into an integrated whole. The project report provides an overview of SIPSE, a section that traces the project from problem definition to project conclusion, details on the background and origins of the project, a full description of the project, and an evaluation and project results. Appendices contain detailed course descriptions and time lines for all SIPSE courses, lists of labs and joint presentations, and a discussion of the notational, terminological, and stylistic differences between mathematics and physics. (DDR)

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SUMMARY

Many capable lower division engineering and physics students are needlessly failing, not due to their own weaknesses, but rather due to the structure of the engineering calculus and physics sequences. These sequences are out of synch with each other — much of the needed mathematics is not covered until after it is needed. Furthermore, the traditional physics preparatory course does not adequately prepare students for the physics sequence. Diablo Valley College's Special Intensive Program for Scientists and Engineers replaces the traditional sequences with a single sequence that combines the two subjects into an integrated whole. It is team taught by a mathematician and a physicist. Students first take Calculus I together with a new introductory physics course. Next they take Calculus III (temporarily bypassing Calculus II) together with Physics I. Topics are resequenced so that the necessary math is in place when it is needed. SIPSE students attend formal study groups. These study groups provide the support structure necessitated by the demands of the program itself.

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Appendix II contains detailed course descriptions and time lines for all SIPSE courses, as well as lists of labs and joint presentations. We have attempted to provide enough information that an adopter of our model could recreate that model without reinventing it.

Appendix III contains a discussion of the notational, terminological and stylistic differences between mathematics and physics.

Appendix IV contains Dr. Eve Kelemen's independent evaluation.

EXECUTIVE SUMMARY

Project Title: A Team Taught Interdisciplinary Approach to Physics and Calculus Education
Grantee: Diablo Valley College, Pleasant Hill, CA 94523
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A. PROJECT OVERVIEW

Many capable lower division engineering and physics students are needlessly failing, not due to their own weaknesses, but rather due to the structure of the engineering calculus and physics sequences. These sequences are out of synch with each other; the calculus needed in physics is not covered until after it is needed. Diablo Valley College's Special Intensive Program for Scientists and Engineers (SIPSE) replaces the traditional sequences with a single sequence that combines the two subjects into an integrated whole. The sequence is team taught by a mathematician and a physicist.

B. PURPOSE

Physics and engineering students need vectors, vector calculus and multivariable calculus as soon as possible. This mathematics is the natural tool of Engineering Physics I and II. In the traditional sequences students do not study this mathematics until a semester after it is needed in their physics courses:

term	math	physics
fall semester, freshman year	Calculus I (derivatives and some integrals)	none
spring semester, freshman year	Calculus II (integration techniques and applications, series, differential equations)	Engineering Physics I (mechanics) *uses much of Calculus III material*
fall semester, sophomore year	Calculus III (vector and multivariable calculus)	Engineering Physics II (electricity and magnetism) *uses material from the end of Calculus III, material that may not be covered*

Requiring physics students to learn mechanics without a background in vector and multivariable calculus imposes an unnecessary hurdle on them. Many do not survive.

In addition to having an insufficient mathematics background, the traditional Physics I student also has an insufficient physics background. Many high school physics courses do little to prepare the student for the

rigors of the engineering physics sequence, and most colleges lack a dedicated engineering physics preparatory course.

C. BACKGROUND AND ORIGINS

Diablo Valley College, a large community college in the San Francisco Bay Area, transfers more students to the University of California system than any other school. At DVC, David Johnson and Oshri Karmon found that too many students that should have succeeded in the calculus and physics sequences failed them. We obtained state funding, followed by FIPSE funding, that allowed us to design and implement a team taught integrated calculus/physics sequence.

D. PROJECT DESCRIPTION

SIPSE's defining characteristics are:

- the resequencing of physics and calculus so that the students' mathematics and physics courses complement each other
- the integration of physics and calculus in a sequence of courses team-taught by a mathematician and a physicist
- the utilization and discussion of both mathematics and physics notations and approaches
- the utilization of cooperative-learning study groups
- the creation of a new introductory physics course

SIPSE students take their calculus courses in a nontraditional order; they first take Calculus I together with the new introductory physics course. Next they take Calculus III (temporarily bypassing Calculus II) together with Physics I. SIPSE also alters the sequence of calculus and physics topics within a given semester. Topics are resequenced so that the necessary math is in place when it is needed. This aides the students' progress in physics because it allows her to use the appropriate math tools, and it aides her progress in mathematics because the mathematics is put into context as soon as it is covered. It also allows the instructors to make the students thoroughly familiar with both math and physics notations, terminologies and approaches. Furthermore, it is no longer necessary for the physics instructor to teach math along with the physics, so a significant amount of time is freed up.

SIPSE classes are team taught by a mathematician and a physicist. Both instructors are present during class time. This allows the physicist to augment the mathematician's presentation with a discussion of applications, and it allows the mathematician to contribute to the physicist's presentation by discussing appropriate mathematics and notational differences. It also allows the physicist and the mathematician to jointly discuss the many topics where their two subjects converge.

All SIPSE students are required to attend formal study groups. These study groups borrow heavily from Uri Treisman's groundbreaking work in cooperative-learning study groups. They provide the support structure necessitated by the demands of the program itself, and they create a commitment to excellence and a sense of security at a point where beginning students are questioning their abilities.

E. EVALUATION/PROJECT RESULTS

Our independent evaluator reports a number of differences between SIPSE students and non-SIPSE students. SIPSE students had significantly higher success rates and significantly lower withdrawal rates in spite of the fact that their mathematics skills were inferior before entering the program. In three of the four involved courses, SIPSE students had significantly higher grades; in the fourth course there was no significant difference. SIPSE students reported significantly more perceived changes in their study habits and the amount of time spent studying than did non-SIPSE students.

The SIPSE instructors' formal evaluation found that SIPSE Physics I students performed better on common final exam questions. Also, SIPSE students' scores on the Wells-Swackhamer Force Concept Inventory and Mechanics Baseline tests compare favorably with those of students from much more selective schools — Harvard University and Arizona State University.

The SIPSE instructors have observed a number of differences between the SIPSE student and the non-SIPSE student. The SIPSE student is stronger in the post-SIPSE lower division math and physics courses. The SIPSE student is more confident in his or her academic abilities. The SIPSE student is more likely to transfer to a top-level four-year institution, and more likely to graduate in engineering or science. Women and minorities are more likely to both enroll in and succeed in SIPSE than they are in the traditional program.

The SIPSE faculty have presented SIPSE at a eleven national conferences. Furthermore, the project director organized the Consortium for the Combined Instruction of Mathematics and Physics, whose members are from engineering schools, four year liberal arts colleges and community colleges from across the country. The consortium aims to widely publicize the success of combined calculus/physics courses.

The Special Intensive Program for Scientists and Engineers has not been institutionalized, in spite of its success. It was last offered during Spring 1996, the last semester of FIPSE funding. There are no plans to offer it again. Diablo Valley College's President decided that it is not cost effective.

A. PROJECT OVERVIEW

Diablo Valley College's Special Intensive Program for Scientists and Engineers (SIPSE) started when Oshri Karmon, a physicist, and David Johnson, a mathematician, discovered that they shared the same long-held observation—too many adequately prepared, dedicated, able students fail the engineering calculus and physics sequences. After auditing each others' courses, we identified two causes:

- the calculus and physics sequences are so out of synch with each other that they unnecessarily hinder the students' progress
- students are not adequately prepared for the physics sequence by the traditional prerequisite course

DVC's sequences are structurally typical of those found throughout the United States, and these difficulties are commonplace.

SIPSE offers lower division engineering, physics and other science majors an option to the traditional stand-alone calculus and physics sequences—a single sequence, team taught by a mathematician and a physicist, that combines the two subjects into an integrated whole. It radically reorders topics so that the two subjects mesh and reinforce each other. The sequence incorporates a new physics preparatory course that is specifically designed to prepare students for the rigors of the physics sequence.

SIPSE students enjoy significantly increased success rates within the two sequences and in their more advanced math and physics courses.

B. PURPOSE

Physics and engineering students need vectors, vector calculus and multivariable calculus as soon as possible. This mathematics is the natural tool of Engineering Physics I and II (mechanics, and electricity and magnetism, respectively). However, most students don't study this mathematics until a semester after it is needed in their physics courses. Consider the following traditional sequence:

term	math	physics
fall semester, freshman year	Calculus I (derivatives and an introduction to integrals)	none
spring semester, freshman year	Calculus II (integration techniques and applications, series, differential equations)	Engineering Physics I (mechanics) *uses much of Calculus III material*
fall semester, sophomore year	Calculus III (vector and multivariable calculus)	Engineering Physics II (electricity and magnetism) *uses material from the end of Calculus III, material that may not be covered*

Under this and other typical formats, the Engineering Physics I student doesn't study vector and multivariable calculus until a semester after he needs it. As a result, physics teachers teach some of this math in their already overly-full course, and they do without the rest; instead, they apply less appropriate but more basic tools.

The Engineering Physics II student *might* study the mathematics that she needs during the semester that she needs it. However, this math (divergence, curl, Green's Theorem, Stokes' Theorem and Gauss' Theorem) is not covered until the very end of the semester *if it is covered at all.* Again, physics teachers teach some of this math themselves and do without the rest.

Undoubtedly, physicists have always viewed this approach as necessary. In order to take three consecutive semesters of lower division physics, a student must take Engineering Physics I no later than his second semester. That allows Calculus I to be a prerequisite and Calculus II to be a corequisite; it does not allow Calculus III to be taken in time.

Requiring a physics student to learn mechanics without a background in vector and multivariable calculus is like requiring a craftsman to carve wood with a screwdriver rather than a chisel. While some students survive this experience, many don't. The survivors may learn the necessary math in the following semester, but the mathematicians' notation, terminology and approach is different enough from the physicists' that many survivors do not recognize it. The need for this mathematics increases when the student takes upper division physics. Thus, the traditional calculus and physics sequences have a built-in mathematics deficit, a deficit that will neither go away nor become unimportant.

In addition to having an insufficient mathematics background, the traditional Physics I student also has an insufficient physics background. At most institutions the prerequisite is either high school physics or the first semester of the non-majors physics sequence. Many of the students that had taken physics in high school had an overly minimal exposure to the subject, and the non-majors course does little to help students gain the necessary skills and learn the necessary concepts. Thus, our FIPSE proposal included the development of a one semester calculus based preparatory course is taught concurrently with Calculus I. The course, called "Introduction to Engineering Physics," is a composite of successful physics education research findings and it provides the skills necessary to succeed in lower division physics.

C. BACKGROUND AND ORIGINS

Diablo Valley College, a large community college in the San Francisco Bay Area, has a strong transfer program. Traditionally DVC transfers more students to the University of California system, and to UC Berkeley in particular, than any other school. Furthermore, UC Berkeley actively redirects students to DVC.

SIPSE's original co-directors, David Johnson and Oshri Karmon, had significant experience in teaching the engineering calculus and physics sequences. Over the years, we had found that too many students that should have succeeded in those sequences failed them. We also found that those that succeeded had overwhelming difficulties in adapting to their transfer institutions, and too many failed to complete their majors.

We obtained state funding that allowed us to audit each others' courses and to design and implement a team taught integrated calculus/physics sequence. Unfortunately, California's economic crisis eliminated our funding after one year, and our experimentation ceased. The success of our initial offering and the encouragement of our Dean of Instruction prompted us to apply for further funding.

After obtaining a FIPSE grant and reinstituting our experimental program, we enjoyed the support of our Dean of Instruction, our campus President, and the Mathematics Department. Then a tragedy struck and our Dean of Instruction died. Mr. Karmon encountered personal problems that forced him to resign as SIPSE's co-director, although he was able to continue his involvement in designing and implementing the program. Furthermore, our campus President retired and our district Chancellor resigned. This administrative upheaval caused SIPSE great difficulties.

D. PROJECT DESCRIPTION

SIPSE's goals are to:
- increase the success rate in the calculus and physics sequences without decreasing content or expectations
- increase the number of students, including underrepresented minority students and women, who transfer to four year universities in science and engineering, and increase the probability that such students will successfully complete their degrees
- articulate curricula content between the mathematics and physics departments and develop a unified approach to calculus and physics education
- be of generic design so that it can be easily adopted by other colleges and universities.

We have met these goals.

SIPSE's defining characteristics are:
- the resequencing of physics and calculus, and the rearrangement of the three semesters of calculus, so that the students' mathematics and physics courses complement each other
- the integration of physics and calculus in a sequence of courses team taught by a mathematician and a physicist
- the utilization and discussion of both mathematics and physics notations and approaches
- the utilization of cooperative-learning study groups
- the creation of a new introductory physics course

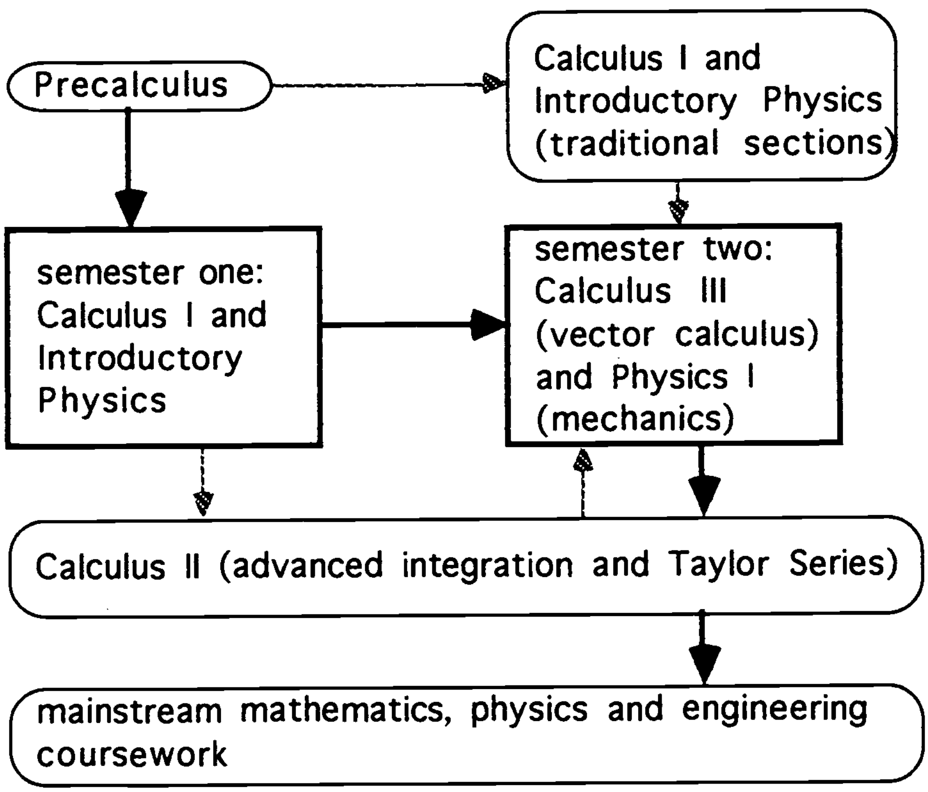
Justification for each of these features, as well as the effects of their implementation, will be discussed.

PROGRAM STRUCTURE

SIPSE is a two semester program. Semester I combines Calculus I and a new physics preparation course of our own design ("Introduction to Engineering Physics"). Semester II combines Calculus III (vector calculus) and Engineering Physics I (mechanics). Each semester consists of a single course that combines calculus and physics, team-taught by a mathematician and a physicist. After completing this program, SIPSE students take Calculus II and the more advanced lower division courses (Linear Algebra, Differential Equations, Electricity and Magnetism, and Modern Physics) in a traditional non-integrated format.

This two semester program is structurally flexible. Students can participate in Semester I and then transfer out of SIPSE into the traditional sequences, or visa-versa. We designed this flexibility into SIPSE because Diablo Valley College is a community college, and students have many outside constraints (jobs, families, etc.) on their lives.

The following flow chart illustrates SIPSE's structure. The square boxes describe SIPSE itself, while the rounded boxes refer to the surrounding courses. The heavy arrows describe the most typical sequence, while the lighter arrows describe optional sequences.



PROJECT SCALE

At first, Johnson and Karmon taught one SIPSE section each semester, alternating between SIPSE's Semester I and Semester II. These sections were offered as an alternative to the traditional calculus and physics sequences; in particular, there were approximately eleven sections of Calculus I, two sections of Calculus III, and three sections of Physics I each semester. There were no other sections of Introduction to Engineering Physics; that course was strictly a part of SIPSE. Student interest in SIPSE was rather low, and we had to actively recruit students.

After two years, we brought in a second mathematician, Rachel Westlake, and a second physicist, James Ardini, and we doubled our offerings. Each term we offered a section of Semester I and a section of Semester II, and those sections filled easily. Furthermore, the new introductory physics course surpassed its original SIPSE role and was now institutionalized. It became the prerequisite for all sections (both traditional sections and SIPSE sections) of Physics I.

To compensate for the time spent team teaching, each of the four SIPSE instructors received reassigned time, paid for by the FIPSE grant. The mathematics department was easily able to absorb the effects of this reassigned time, but the much smaller physics department found that it was a significant drain on its resources. Furthermore, several physics faculty retired during the intervening years, and they were not replaced immediately. Thus, the drain that SIPSE placed on the physics department's resources became more pronounced.

THE RESEQUENCING OF PHYSICS AND CALCULUS

SIPSE students take their calculus courses in a nontraditional order; they take their vector and multivariable calculus together with mechanics and they take the traditional "middle" calculus course the following semester. SIPSE students also take a new physics prep course together with Calculus I.

term	math	physics
semester one of SIPSE	Calculus I (derivatives and an introduction to integrals)	*combined with* Introduction to Engineering Physics
semester two of SIPSE	Calculus III (vector and multivariable calculus)	*combined with* Engineering Physics I (mechanics) *uses much of Calculus III material*
after completing SIPSE	Calculus II (integration techniques and applications, Taylor series, differential equations)	Engineering Physics II (electricity and magnetism) *uses material from the end of Calculus III*

This resequencing has caused SIPSE students no damage; in fact it has greatly increased their performance. Diablo Valley College allowed some non-SIPSE students to take calculus in this order. None of them were

taking Engineering Physics I, and they all did quite poorly. It appears that combining Calculus III and Engineering Physics I is a necessary condition for the success of this calculus resequencing.

In addition to improving students' performance in physics, this I/III/II calculus resequencing has some other advantages. It places vector calculus immediately prior to Linear Algebra, which makes the more abstract Linear Algebra treatment of vectors more understandable. (In the traditional sequence, many students take Linear Algebra before they take vector calculus.) It also places Taylor series immediately prior to Differential Equations, which ensures that students remember their series well enough to use them in Differential Equations.

SIPSE not only alters the traditional sequence of the three semesters of calculus, it also alters the sequence of calculus and physics topics within a given semester. Topics are resequenced so that the necessary math is in place when it is needed. This aides the students' progress in physics because it allows her to use the appropriate math tools, and it aides her progress in mathematics because the mathematics is put into context as soon as it is covered. It also allows the instructors to make the students thoroughly familiar with both math and physics notations, terminologies and approaches. Furthermore, it is no longer necessary for the physics instructor to teach math along with the physics, so a significant amount of time is freed up. This extra time is spent:

- covering the often-skipped divergence, curl, Green's , Stokes' and Gauss' Theorems
- discussing the application of calculus to physics
- covering the statistics used in physics

We found it necessary to combine calculus and physics into one integrated course, rather than merely to link together a section of calculus and a section of physics, for a number of reasons. Even though we radically resequence the calculus, it is still difficult to cover the necessary math in time for its use in physics. By combining the courses we allow ourselves a great deal of time flexibility, without which we would not succeed in delivering the necessary math on time. For example, we spend most of the first few weeks of Semester II on mathematics (in particular, on vector algebra and vector calculus); the physics portion of the course is minimal until this basic material is finished. Other advantages are discussed in the "Team Teaching" section of this document.

TEAM TEACHING

SIPSE classes are team taught by a mathematician and a physicist. Both instructors are present during class time. This allows for several different modes of interaction:

- The physicist completes the mathematician's presentation with an extensive presentation of the applications of that topic to physics. Examples: vectors; line integrals and work.
- The physicist contributes to the mathematician's presentation by discussing applications that the student will encounter in a future physics or engineering course. Examples: divergence, gradient and curl as used in electricity and magnetism; multivariable optimization techniques as used in Lagrangian and Hamiltonian physics.
- The mathematician contributes to the physicist's presentation by briefly revisiting previously covered math or by discussing notational and terminological differences and differences of style.
- The physicist and the mathematician jointly discuss a topic. Examples: conservative vector fields; analyzing 3-dimensional motion with u_r & u_θ and with T, N and B; centers of mass and moments of inertia with single and multiple integration.

These different modes of interaction increase the student's ability to apply mathematics to physics, and to understand the inherent interconnectedness of the two subjects. We believe that this is necessary for student success, and that it is discouraged by the traditional approach that involves separate, out-of-synch sequences in calculus and physics that use different notations, terminologies and styles.

There is an additional mode of interaction that occurs outside of class time (i.e. during break, before and after class, and during study groups). Frequently, the two instructors get into conversations where we discuss our two fields' differences and similarities, or where one teaches the other something new. Invariably, students are drawn into these discussions, and they benefit from them tremendously. These give-and-take sessions impart a graduate seminar feel to the class, and they greatly encourage active participation in the class by the students.

Team-teaching allows the instructors to alter the ratio of math time to physics time on a daily basis. When a certain math topic must be covered before physics can go any further, the majority of the time can be spent on math. When that topic is finished, the time shifts over to physics. (Naturally, the students are told of time shifts in advance.) While these

time shifts do not pervade the course, and a regular schedule is usually maintained, they greatly increase the instructors' abilities to interweave the two subjects. We have found that the number of topics shared by the two fields as well as the number of field-specific prerequisites make this time flexibility invaluable. It would be quite difficult (perhaps impossible) to combine mechanics with vector and multivariable calculus without team teaching—the goal of resequencing topics so that the two subjects mesh imposes significant demands on the course schedule.

Only some instructors can meet the demands of team teaching. It is valuable for the physics instructor to have a strong background in math, because that instructor periodically must leave behind the traditional approach. The traditional approach was necessitated by the students' lack of sufficient math background; in the SIPSE model, the students have no such deficit, and the instructor must be knowledgeable and flexible enough to know when and how to apply a more advanced mathematical tool not covered in the text. It would certainly be helpful if both instructors had a strong background in each other's field, but we believe that it is more important that the physics instructor has a strong math background.

It's crucial that both instructors are flexible. Team teaching is very different than the traditional mode, and the instructors must relinquish absolute control over the class. This control must now be shared — test dates, topic scheduling, and in-class interactions must all be mutually agreeable.

Team teaching has a serious administrative down side. It's expensive, because both instructors must receive load credit for the class. With the traditional separate calculus and physics courses, the math instructor gets x hours of load credit for teaching calculus, and the physics instructor gets y hours of load credit for teaching physics. With the team taught SIPSE courses, each instructor is in class $x + y$ hours, and this must be compensated. Without this extra compensation, a team taught program would be taught only by those that are so committed that they would donate their time, and this can only lead to instructor burn-out and the program's demise. We believe that the students' increased success rates (both within the program and after completing the program) more than compensate for this extra expense.

Team teaching has another administrative down side—scheduling. Not all instructors can do well in a team teaching situation, and some consideration of this must occur when assigning faculty. Furthermore,

classrooms tend to be viewed as the property of certain departments, and a team taught program requires two departments to share space.

Last but not least, team teaching is fun. It's exhilarating to learn to work well with another instructor, and it's fulfilling to see students learn the mathematics and its application all at once. And the two subjects belong together. After all, they were originally one subject (Newton's "Natural Philosophy") and they have been artificially split apart.

COOPERATIVE-LEARNING STUDY GROUPS

All SIPSE students are required to attend scheduled study groups for four hours per week (broken up into two two-hour sessions). Each group consists of four to six students and a group leader; the group leader is either an advanced SIPSE graduate or an upper division student from nearby UC Berkeley. The groups meet simultaneously, and one of the two instructors is always present at the group meetings. In our case, this is not only educationally desirable but also legally necessary—the instructor of record must always be present.

Typically, the groups will have an assignment that is designed to take less than the full two hours; the remaining time is for students to help each other and to get help from the group leader on their ongoing work. At times, the entire group session is reserved for help.

The group assignments take a number of different forms:

- Some assignments explore the application of mathematics to physics at a level beyond that of the text.
- Some assignments focus only on one subject, but at a level beyond that of the text.
- Some assignments are representative subsets of the students' individual homework assignments. If a group can collectively get through such a group assignment (with the group leader's assistance when necessary) then it is quite likely that the student will have few problems with her individual assignment.

The study groups borrow heavily from MacArthur Award winner Uri Treisman's groundbreaking work in cooperative-learning study groups. (It is important to note that SIPSE groups are not optional add-ons to all sections as are Dr. Treisman's; instead, they are an integral part of the course.) Triesman found that successful Berkeley science students tend to belong to study groups, and that unsuccessful ones do not. The community college transfer student is usually unaware of the value of a study group

and thus upon transfer becomes a loner who lacks access to a significant resource. The community college's comparative lack of competitiveness does not encourage the formation of study groups, and the commuter aspect of a community college actually discourages their formation.

The step from Calculus I to Calculus III is a big step; Calculus III is a very sophisticated course. This step is manageable because the students use the material from Calculus III in physics on a daily basis—the physics reinforces the calculus. Furthermore, the study groups provide the support structure necessitated by the demands of the program itself.

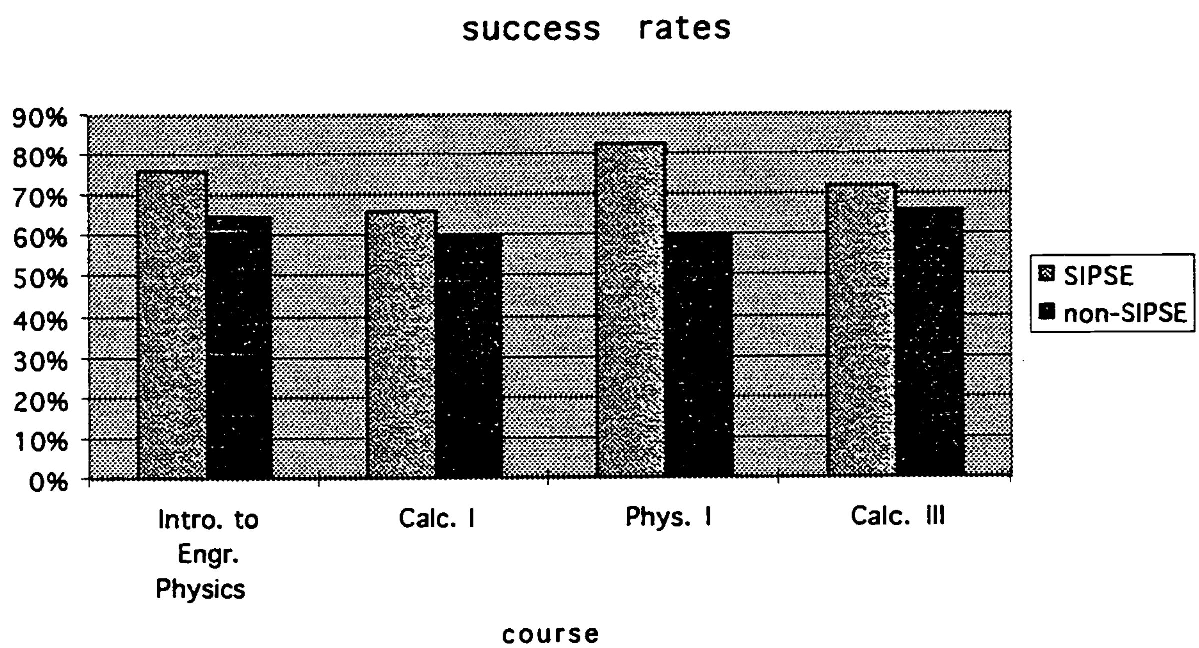
The study groups create a sense of security and belonging at a point where beginning students are questioning their abilities. They help create a sense of community and a commitment to excellence. SIPSE students report that they continue to participate in study groups in their more advanced coursework at DVC, as well as after they transfer to a four-year institution. They also report that their original SIPSE study groups remain intact after SIPSE is over; students enroll in advanced math and physics courses with their study groups intact, and they transfer with their study groups intact.

E. EVALUATION/PROJECT RESULTS

INDEPENDENT EVALUATION

Dr. Eve Kelemen performed our independent evaluation. Her complete report is given in Appendix IV. A summary of that report is given here, along with the project director's comments.

Part I — A comparison of the SIPSE students' success rates and withdrawal rates with those of the non-SIPSE students.



We define success as receiving an A, B or C at the end of the semester.

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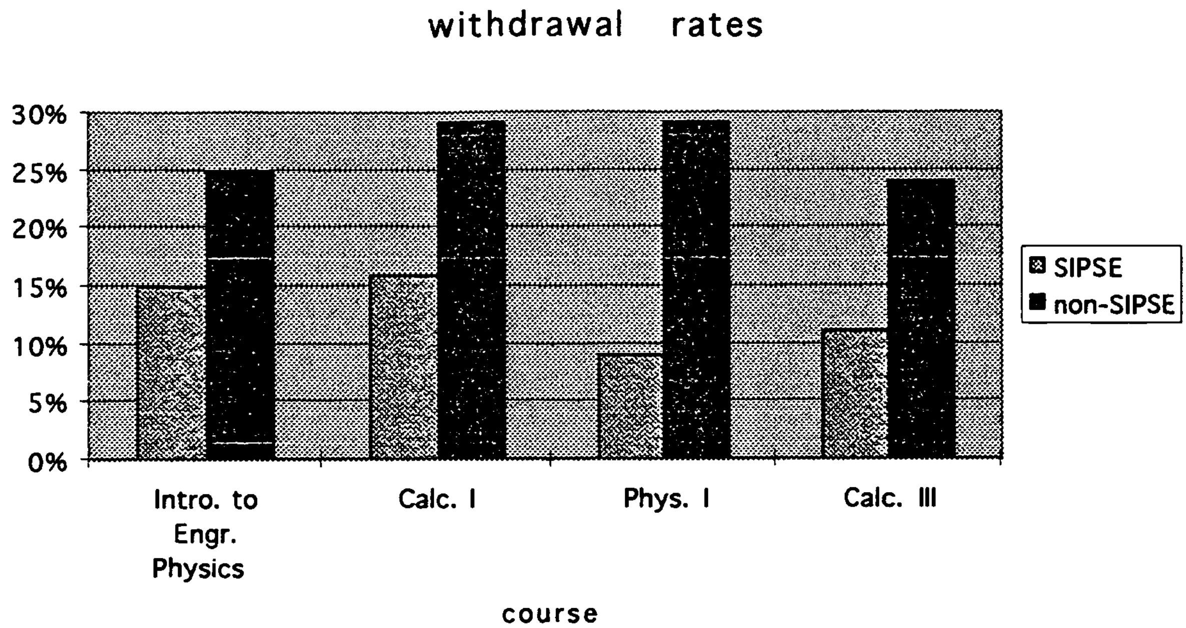

Clearly, SIPSE has had a profound effect on student success rates and withdrawal rates. Dr. Kelemen points out that this was in spite of the fact that the SIPSE students' mathematics skills were inferior to those of the non-SIPSE students at the time of their arrival at Diablo Valley College, as demonstrated by performance on their mathematics placement tests.

The most profound effect occurred in Physics I. This is understandable, in that both the creation of a new physics preparatory course ("Introduction to Engineering Physics") and the resequencing of the three semesters of calculus were designed to impact Physics I. The Introduction to Engineering Physics comparisons are especially telling in that the same instructor taught all sections of both the SIPSE and non-SIPSE versions of that course, and he deliberately attempted to teach them in the same way as much as possible. (The non-SIPSE sections were not team taught but they did require concurrent enrollment in Calculus I.) The calculus comparisons are not as profound as the physics comparisons, but they are still quite respectable. This too is understandable — students benefit more in physics from having the necessary math in place when it is needed than they benefit in math from learning how to apply their math.

The data in the above charts compares all SIPSE sections with all non-SIPSE sections from the same semesters. (Somehow, one semester was inadvertently omitted.)

Part II — A comparison of the SIPSE students' grades with those of the non-SIPSE students

course:	SIPSE students had:
Intro. to Engr. Physics	significantly higher grades
Calculus I	no significant difference in grades
Physics I	significantly higher grades
Calculus III	significantly higher grades

In three of the four courses (Introduction to Engineering Physics, Physics I and Calculus III) SIPSE students had significantly higher grades than did non-SIPSE students. Again, this was in spite of the fact that the SIPSE students' mathematics skills were inferior to those of the non-SIPSE students at the time of their arrival at Diablo Valley College, as demonstrated by performance on their mathematics placement tests.

It is also worth noting that it is the opinion of the four SIPSE instructors that the SIPSE courses were taught at a more rigorous and demanding level than the non-SIPSE courses. (Introduction to Engineering Physics was taught at the same level, as discussed above.) Furthermore, SIPSE students had significantly higher grades in Calculus III in spite of the fact that most had one less semester of mathematics than the non-SIPSE students. (The non-SIPSE students had taken Calculus II, while most of the SIPSE students had not.)

Part III — An analysis of SIPSE students' and non-SIPSE students' responses to an anonymous questionnaire

Each term, SIPSE and non-SIPSE students were queried regarding perceived changes in their study habits, their commitment to their major, and the amount of time spent studying. They were also asked if study groups were of value to them (the non-SIPSE students were asked if they participated in study groups, and if so if they were of value to them) and to evaluate the mathematics and physics portions of the course (the non-SIPSE students were asked to evaluate their math course or their physics course, as appropriate). The evaluation of the mathematics portions of the course is not yet complete; we're collecting more non-SIPSE evaluations at the end of the Fall 1996 semester.

SIPSE students had:	in the area of:
significantly more change	study habits
no significantly different change	commitment to their major
significantly more change	amount of time spent studying
found significant value	study groups
there was no significant difference	the evaluation of the physics courses

The SIPSE instructors observed tremendous improvements in study habits and in the amount of time spent studying. We also observed that these improvements translated into markedly better performance in the advanced lower division math and physics courses at Diablo Valley College, as well as in the upper division work at the transfer institutions.

Part IV — An overview of the SIPSE students' written comments on the anonymous questionnaire

The comments were virtually all positive. A selection of comments is given in Appendix IV.

IN-HOUSE EVALUATION

Our in-house evaluation consisted of the use of common final exam questions in the FIPSE and the non-FIPSE sections of Physics I, and the administration of the Wells-Swackhamer Force Concept Inventory and Mechanics Baseline tests to SIPSE physics sections.

Introduction to Engineering Physics

The Force Concept Inventory pretests and post-tests were employed to measure the success of the course's mechanics component. The pretest average over the past three years has been 35% and the post-test average 65%.

A follow-up study has been conducted to find out about transfer and retention rates for students who took this course. Ninety percent of the course graduates passed Physics I.

Physics I Common Exam Questions

During Fall semester of 1994, the Physics Department included a common core of questions in all Engineering Physics I final exams. Those questions were authored and corrected by a physics instructor who was not teaching the course, and who did not divulge the questions to instructors who were teaching the course. This common core consisted of ten multiple choice

questions administered to five sections. The following analysis is based upon those questions, as well as retention, i.e., the percent of the students who completed the semester. Since higher retention and higher scores were both desired, we decided that a crude measure of performance would be given by simply multiplying retention rate by section average.

Sections	1	2	3	4	SIPSE
retention including early withdrawal students	38%	45%	44%	40%	89%
retention excluding early withdrawal students	63%	68%	65%	60%	96%
average score on common questions	39%	47%	47%	47%	39%
section performance (retention x average)	0.15	0.21	0.21	0.19	0.35
class average from final grade roster	81%	60%	60%	73%	69%

TABLE 1: PHYSICS I COMMON EXAM QUESTIONS

Several non-SIPSE sections had higher average scores on the common questions. However, those sections had already lost most of their students. The SIPSE section's average score was achieved with hardly any loss of students. The "section performance" score clearly demonstrates this.

Physics I Wells-Swackhamer Tests

The Wells-Swackhamer Force Concept Inventory and Mechanics Baseline pretests and post-tests were given to SIPSE Physics I students during Spring and Fall 1995, and Spring 1996. The results are given below. For comparison purposes, scores for Arizona State University and Harvard University are also given below; these scores are taken from The Physics Teacher (volume 30, March 1992, pg. 145). The DVC SIPSE students compare favorably with students from these much more selective schools. It is important to note that some of our students had previously seen the Force Concept Inventory test during their SIPSE Introduction to Engineering Physics course while, presumably, those from the other schools had not. However, the post-tests can be compared, since all post-test students had seen the tests before, with the exception of Harvard Honor students. The results are summarized in Table 2, and are detailed in Table 3.

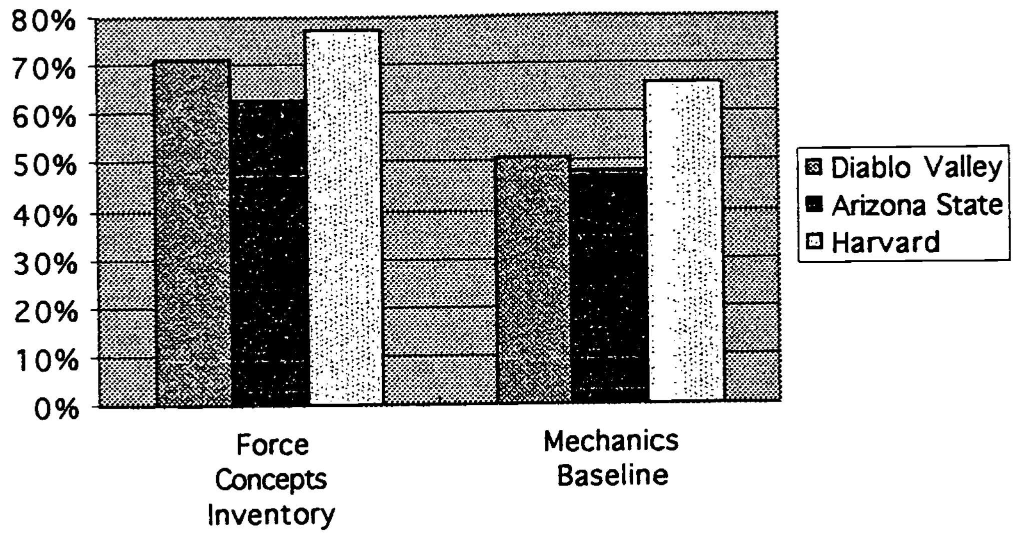

TABLE 2: WELLS-SWACKHAMER TEST SUMMARY

	Force Concept Inventory Pretest (Std. Dev.)	Force Concept Inventory Posttest (Std. Dev.)	Mechanics Baseline Pretest (Std. Dev.)	Mechanics Baseline Posttest (Std. Dev.)	Posttest number of students N
DVC Spring 95	66% (17)	71% (17)	45% (17)	N.A.	18
DVC Fall 95	59% (19)	66% (19)	40% (10)	49% (16)	17
DVC Spring 96	70% (14)	75% (12)	47% (14)	53% (17)	16
DVC overall	65%	71%	44%	51%	51
Arizona State	52% (19)	63% (18)	N.A.	48% (15)	139
Harvard	N.A.	77% (15)	N.A.	66% (14)	186
Harvard Honors	N.A.	N.A.	N.A.	77% (11)	75

TABLE 3: WELLS-SWACKHAMER TEST DETAILS

Some of the students in SIPSE Semester II took SIPSE Semester I, and some didn't. Those that didn't had varying backgrounds; many had taken Calculus II. We compared the Semester II performance of the continuing SIPSE students with that of the new SIPSE students. The results are summarized in Table 4, and are detailed in Table 5.

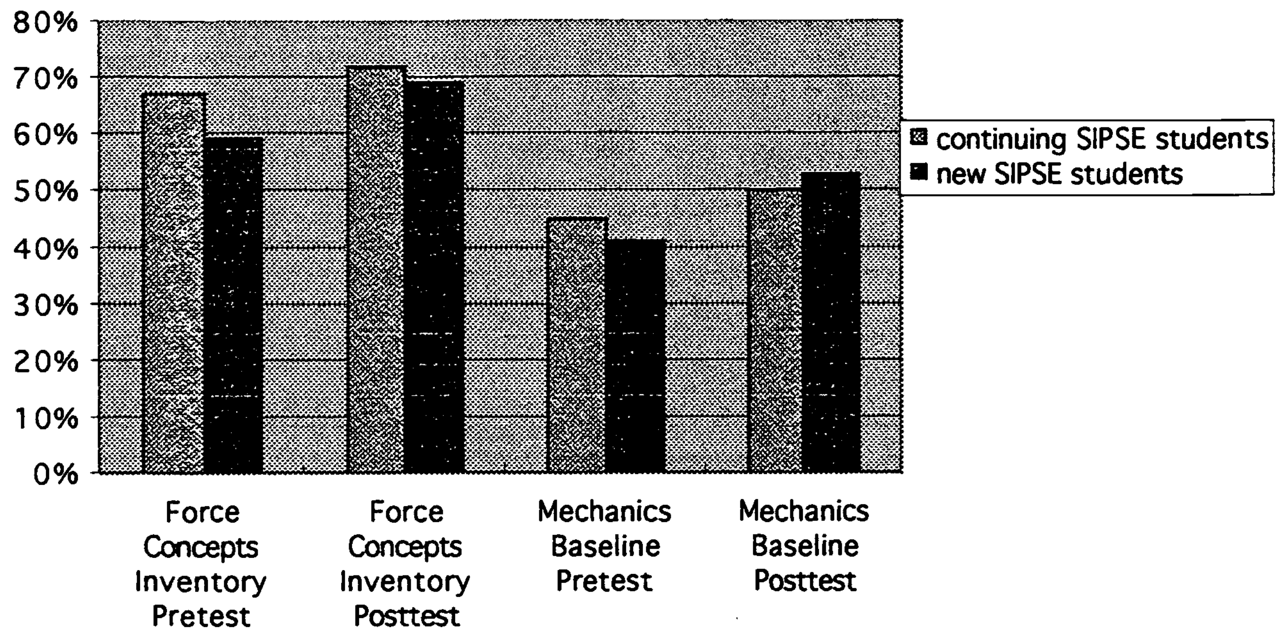

TABLE 4: CONTINUING VS. NEW SIPSE STUDENTS

	Force Concepts Inventory Pretest (Std. Dev.)	Force Concepts Inventory Posttest (Std. Dev.)	Mechanics Baseline Pretest (Std. Dev.)	Mechanics Baseline Posttest (Std. Dev.)	Posttest number of students N
Spring 95 continuing	70% (16)	75% (15)	48% (16)	N.A.	10
new	61% (18)	68% (18)	41% (18)	N.A.	8
Fall 95 continuing	61% (19)	65% (19)	40% (10)	46% (15)	12
new	53% (20)	67% (20)	39% (9)	53% (23)	5
Spring 96 continuing	71% (13)	76% (14)	47% (17)	54% (19)	13
new	65% (6)	76% (4)	46% (11)	53% (10)	3
overall continuing	67%	72%	45%	50%	35
new	59%	69%	41%	53%	16

TABLE 5: CONTINUING SIPSE STUDENTS VS. NEW SIPSE STUDENTS-DETAILS

FACULTY OBSERVATIONS

After four years of teaching SIPSE, the instructors involved all agree that the students who enroll in SIPSE are not exceptional students. In fact, our evaluator has indicated that SIPSE students have lower math placement test scores than do the non-SIPSE students. We see only two differences between the beginning SIPSE student and the beginning non-SIPSE student:

- All SIPSE students have passed Precalculus. Non-SIPSE students are "required" to have passed Precalculus, but the requirement is not enforced.
- All SIPSE students opt to take part in a program that is, according to the word of mouth, intense. Furthermore, the Special Intensive Program for Scientists and Engineers (SIPSE) is labeled "intensive."

After completing SIPSE, there are a number of differences between the SIPSE student and the non-SIPSE student:

- The SIPSE student is stronger than the non-SIPSE student in the remaining lower division math and physics courses (Linear Algebra, Differential Equations, Electricity and Magnetism, and Modern Physics).
- The SIPSE student is more confident in his or her academic abilities.
- The SIPSE student is more likely to transfer to a top-level four-year institution than is the non-SIPSE student
- The SIPSE student is more likely to graduate in engineering or science than is the non-SIPSE student. (Our formal evaluation was to have compared SIPSE and non-SIPSE students' performance at the transfer institution. However, we were not able to do this, because the transfer institutions will not release the necessary data.)
- Women and minorities are more likely to both enroll in and succeed in SIPSE than they are in the traditional program.

These differences are strictly the observations of the SIPSE faculty. With the exception noted, they were not a part of the evaluation procedure agreed upon by Diablo Valley College and FIPSE, and our evaluator did not investigate them. However, we would very much like to expand our evaluation and determine if these observations are factual.

Our failures are rare. Often, the only students that don't succeed are those who had non-academic problems (financial, family, etc.). And many of those that don't succeed come back to us the next semester and succeed.

DISSEMINATION

We have presented SIPSE at a number of conferences:

- California Mathematics Council of Community Colleges, Monterey, CA, December 1993 (Mr. Johnson)
- American Association for Higher Education Conference, Washington, D.C., November 1994 (Mr. Johnson)
- Rutgers University, invited speaker, April 1995 (Mr. Johnson)
- Fourth Conference on the Teaching of Mathematics, San Jose, CA June 1995 (Mr. Johnson and Prof. Ostertag, Dutchess Community College, New York)
- Rose-Hulman Institute of Technology's Integrated First Year Curriculum Conference, Staten Island, New York, July 1995 (Mr. Johnson)
- American Association of Physics Teachers Conference, Spokane, WA, August 1995 (Mr. Johnson and Mr. Karmon)
- FIPSE Project Director's Meeting, Washington, D.C., October 1995 (Mr. Johnson, leading a panel discussion)
- Fifth Conference on the Teaching of Mathematics, Baltimore, MD, June 1996 (Mr. Johnson and Profs. Zenor and Shumpert, Auburn University, and Prof. Rex, University of the Puget Sound)
- American Association of Physics Teachers Conference, College Park, MD, August 1996 (Mr. Johnson)
- American Mathematical Society/Mathematics Association of America Joint Conference, Seattle, WA, August, 1996 (Mr. Johnson and Prof. Zenor, Auburn University, and Prof. Jackson, University of the Puget Sound)
- American Mathematical Association of Two Year Colleges, Long Beach, CA, November 1996 (Mr. Johnson and Prof. Zenor, Auburn University)

Furthermore, Mr. Johnson organized the Consortium for the Combined Instruction of Mathematics and Physics. The Consortium's members are from:

- Adirondack Community College (New York)
- Auburn University (Alabama)
- Diablo Valley College (California)
- Dutchess Community College (New York)
- North Seattle Community College (Washington)
- Rose-Hulman Institute of Technology (Indiana)
- State University of New York at Binghampton (New York)
- University of the Puget Sound (Washington)

Each of these schools either has a combined calculus/physics program or is interested in having such a program. Several have FIPSE or NSF grants.

Thanks to funding from the GE Foundation, we had our first annual meeting in San Francisco on August 13-15, 1996.

The consortium has a number of goals:
- Disseminate our findings by giving presentations at both local and high-profile national mathematics conferences, physics conferences, and engineering conferences. As much as possible, each presentation should be given by a team that includes mathematicians, physicists and engineers, from community colleges, liberal arts colleges, and engineering universities.
- Disseminate our findings by setting up web pages where we both describe our programs and their evaluations, and offer instructional materials for downloading.
- Disseminate our findings by publishing papers in mathematics, physics and engineering journals.
- Hold consortium meetings on an annual basis.
- Advertise our web pages and consortium meetings through listservs and professional publications so that we gain members who are interested in starting this type of program.

If the Consortium for the Combined Instruction of Mathematics and Physics continues to receive financial support, then SIPSE and the consortium's other models for combined instruction will continue to be disseminated. Without funding, my dissemination efforts will be sharply curtailed but not eliminated. I plan on submitting an article based on this report to various journals, but speaking trips would be impossible.

PLANS FOR CONTINUATION

The Special Intensive Program for Scientists and Engineers has not been institutionalized, in spite of its success. It was last offered during Spring 1996, the last semester of FIPSE funding. There are no plans to offer it again.

Our campus and district administration has undergone a major personnel change since the awarding of the grant. Our primary administrative partner and supporter, Dr. Elaine Cohen, campus Dean of Instruction, died a year ago. As of this date she has not been permanently replaced. Instead, her office has been filled by a series of temporary replacements. Our campus President, Dr. Phyllis Peterson, retired last year, and our district Chancellor, Dr. Robert Jensen, took a position elsewhere. As a result of this administrative turmoil, SIPSE has not had a consistent administrative advocate.

Our new President, Dr. Mark Edelstein, recently decided not to continue SIPSE. He asked that the following statement be inserted into this report. "The administration has developed a plan to institute aspects of SIPSE in a way which would be more cost effective. So far we've not been able to achieve a consensus on doing that, but will continue to explore ways to implement aspects of SIPSE to improve retention."

The lack of consensus regards faculty credit hours for the team-teaching aspect of SIPSE. The Mathematics and Physics Departments support the continuation of SIPSE, and have agreed on a specific plan for its continuation. This plan requires faculty load credit that is commensurate with SIPSE responsibilities. Dr. Edelstein rejected this plan as not cost effective. The Mathematics and Physics Departments rejected the administration's proposal because of its lack of appropriate load credit, reasoning that SIPSE could only survive if participating faculty receive appropriate load credit.

AFTER THE PROJECT'S COMPLETION

I plan on working with Diablo Valley College's Research Office in investigating the points discussed above under "Faculty Observations," in addition to continuing to work with the Consortium for the Combined Instruction of Mathematics and Physics.

F. CONCLUSIONS

The Special Intensive Program for Scientists and Engineers (SIPSE) has been a tremendous success. We've found a relatively simple way for the calculus and physics sequences to reenforce each other. The students have certainly benefitted, both within SIPSE and after SIPSE. The advantages that they gain in SIPSE seem to last throughout their educational careers. Unfortunately, this model has a number of problems.

Administrators do not see it as cost effective, due to the presence of two faculty in the classroom. The fact that the program generates more students in the following courses doesn't seem to matter. I am aware of a number of interdisciplinary team teaching models, but very very few of them are institutionalized — most are experimental models funded by an outside grant.

Furthermore, team-teaching is something that many faculty simply aren't willing to do. Some of this is due to a general resistance to change, and some is due to academia's departmental structure and the compartmentalized view it creates.

I am heartened by the size of the Consortium for the Combined Instruction in Mathematics and Physics, and the positive response to my own and other consortium members' conference presentations. Perhaps this indicates that resistance is slowly fading.

APPENDIX I
INFORMATION FOR FIPSE

The assistance provided by my FIPSE Program Officers was extremely helpful. They are active participants in their projects and their contribution is valued. Annual site visits are a real plus.

The annual Project Directors' Conference is also a real plus. It is an excellent conference, but it goes beyond that. It made me feel quite special — honored, even. And it made me feel like a member of a team. When things were not going well at home, those few days in October always brought me out of my slump and gave me new energy.

I found the two-stage application process to be especially sane. It actually helped us construct a better project, too.

I encourage FIPSE to continue funding projects that involve combined calculus/physics courses. Special consideration should be given projects that address the following issues:

cost effectiveness — either by altering the traditional administrative view to include long term student success in the formula, or decreasing costs without decreasing effects
dissemination — Many of my colleagues (nationwide) are opposed to any type of team teaching. Furthermore, the departmental structure and academia's long history of compartmentalization make it especially difficult to maintain an interdisciplinary effort. National dissemination of effective programs could slowly change this.

APPENDIX II
COURSE DESCRIPTIONS

The following course descriptions are meant for mathematics and physics educators. They are provided so that others can recreate SIPSE and mold it to meet their own institutions' needs.

SIPSE'S SEMESTER I: INTRODUCTION TO ENGINEERING PHYSICS AND CALCULUS I

CALCULUS I COURSE DESCRIPTION

While the Calculus I portion of SIPSE differs from the traditional course in both emphasis and curriculum, it is still a fairly standard course. The topics covered are given below, with the less traditional topics in italics.

1. Review of functions
2. Limits and continuity
3. Derivatives
    a. Definition of the derivative
    b. Techniques of differentiation, including product, quotient and chain rules
    c. Derivatives of trigonometric functions
    d. *Derivatives of logarithmic and exponential functions*
    e. Applications of the derivative, including related rates, graphing, and optimization
    f. Rolle's Theorem and the Mean Value Theorem
    g. Antiderivatives *(including the trigonometric, logarithmic and exponential functions)*
4. *Differentials*
    a. *Definition of the differential*
    b. *Euler's method*
    c. *error analysis*
5. Integration
    a. Riemann sums
    b. The definite integral
    c. The Fundamental Theorem of Calculus
    d. The indefinite integral
    e. Integration by substitution
    f. *Use of integral tables*
    g. Average value of a function and the Mean Value Theorem for Integrals

h. Areas between curves

6. *Polar coordinates*

a. *Review of polar coordinates* (initially covered in Precalculus)

b. *Areas in polar coordinates*

Curricular Changes

The inclusion of the differential, Euler's method, error analysis, the derivatives and integrals of logarithmic and exponential functions, the use of integral tables, and polar coordinates constitute the only major changes to our Calculus I curriculum. We inserted these in place of the more traditional applications of integration in order to facilitate the transition to the second semester of SIPSE, which covers vector and multivariable calculus, and mechanics. Furthermore, the physics portion of Semester I covers a number of applications of integration.

Changes of Emphasis

We believe that the most valuable concepts that a physics student can acquire in Calculus I are:

- average and instantaneous rates of change
- the linear approximation of a function
- the differential and its use in error analysis and Euler's Method
- the definite integral as a Riemann sum.

Some of these topics, such as rates of change and Riemann sums, are commonplace in Calculus I courses. However, we emphasize their many applications to physics. Other topics, such as linear approximations, the differential, error analysis, and Euler's method, tend to be covered very briefly if at all.

Average Rates of Change

We emphasized the rate of change interpretation of the slope of a linear function in the function review. To better prepare the students for the language of physics, we use variables other than x and y in both functional notation and graphs and we discuss physical interpretations of those variables and their rates of change. We emphasize delta notation, and we explore the relationship $\Delta y = m\,\Delta x$ (or $\Delta x = m\,\Delta t$).

Limits

We cover limits and continuity with more intuition than rigor. We gain intuition by examining tables and graphs of functions with Mathematica, focusing our attention near the limiting value of the independent variable. This is especially useful in studying the indeterminate forms 0/0 and ∞/∞, where we can study the behavior of the numerator and denominator

separately, and then try to draw conclusions about the quotient. We also use Mathematica to improve understanding of the Squeezing Theorem. Students are expected to be able to determine the values of limits through graphing, tables, and computation.

the Derivative

We introduce the tangent line as the best linear approximation to a "nice" function near a given point. We explore the existence of such a line by using Mathematica to zoom in on the graph of a differentiable function. We estimate the equation of this line by picking points off the nearly-linear portion of the graph and using them to estimate the slope. We then go on to the more standard difference quotient approach to determine the "true" slope, first by creating a table with Mathematica, and then by computing the limit.

We recall the rate of change interpretation of the slope of a linear function, and define the instantaneous rate of change and the derivative. Again we use other variables and we discuss different physical interpretations. In the physics portion of the course, we introduce average velocity. We then develop the concept of instantaneous velocity and the derivative in the calculus portion of the class, and we graph position and velocity functions. These ideas are further reinforced in physics with the aid of motion detectors and Micro-Computer Based Labs (MBLs).

In physics lab, the students obtain an experimental value for g, the acceleration due to gravity. (They have not yet developed the kinematics equations.) We use Euler's Method, in conjunction with Mathematica, to obtain theoretical approximations to the velocity and position of their experiment's object in free-fall at various points in time. We compare this to the experimental data. We then use Euler's method to obtain graphs of position and velocity functions for varying initial conditions. We fit the lines and the parabolas, and obtain approximations to the kinematics equations.

the Differential

Students in the regular calculus sequence have little physical intuition about or knowledge of the differential since the math texts at this level deal avoid differentials. However, beginning physics courses make extensive use of the differential. We introduce differential notation early, with dy representing the change in y coordinates on the tangent line for a given change in x coordinates dx. We emphasize the role of differentials in error analysis.

Integrals

We present antiderivatives as a topic separate from indefinite integrals. The role of initial conditions is discussed. Applications to acceleration, velocity, and position are explored, and, in particular, the kinematics equations are derived rigorously.

We compute areas using inscribed and circumscribed rectangles. In each case, a representative rectangle is drawn, in order to emphasize the importance of both f(x) and Δx in the computation of area. We use Mathematica to evaluate sums for large numbers of rectangles, and then evaluate the limit by hand. We introduce the definite integral notation, but continue to emphasize its interpretation as a sum of objects of the form f(x) dx. Other variables are used, and other physical interpretations are discussed. The Fundamental Theorem is introduced as a means of computing these sums. We discuss the indefinite integral, and integration by u substitution.

Students see a variety of applications of the definite integral, including electrical force due to a linear charge distribution. In each case, the physics is introduced by the physics instuctor, and the limiting case is developed by the calculus instructor. Always, the significance of the f(x), the dx, and the sum is emphasized. Students are encouraged to use Mathematica and the integral tables to evaluate any integrals they do not yet have the tools to do by hand.

The development of calculus as described above promotes the synthesis of the calculus and physics concepts in the program. By the end of the semester, the students easily move back and forth between the two disciplines, and use the ideas of one to solve problems in the other.

INTRODUCTION TO ENGINEERING PHYSICS COURSE DESCRIPTION

Before SIPSE, too many Physics I students had insufficient backgrounds. The prerequisite was either high school physics or the first semester of Diablo Valley College's non-majors physics sequence. Many of the students that had taken physics in high school had an overly minimal exposure to the subject, and the non-majors course at DVC did little to help students gain the necessary skills and learn the necessary concepts. Thus, our FIPSE proposal included the development of a one semester calculus based preparatory course that would be taught concurrently with Calculus I. The course, called "Introduction to Engineering Physics," is a composite of successful physics education research findings and it provides the skills necessary to succeed in the calculus based physics sequence. This course

has surpassed its original SIPSE role and is now institutionalized. It is the prerequisite for all sections (both traditional sections and SIPSE sections) of Physics I.

Introduction to Engineering Physics is allotted seven contact hours per week (four hours lecture/problem solving and three hours laboratory). Concepts are developed through multiple representations following Van Huevelen, spiraling from introductory to advanced problem solving techniques. Groups of students collaborate in solving context-rich problems developed by Heller.

Physics topics were arranged to take advantage of essential concepts from the calculus as soon as they are introduced. For example, a discussion of static versus kinetic friction is used to illustrate and reinforce the concepts of the limit and continuity, and integrals are used to illustrate work and energy applications. This early infusion of calculus into the physics curriculum emphasizes the inherent interconnectedness of the two subjects, and provides the students with a stronger background when they start the engineering physics sequence.

The topics covered are given below.

1. Greek astronomy
   a. Using geometry and algebra
   b. Calculating radii and distances for the earth, moon and sun
2. Geometrical optics
   a. Mirrors and lenses
3. Mechanics
   a. Introductory vector algebra
   b. Calculus-based kinematics and Euler's method
   c. Momentum and Newton's laws
   d. Force as the derivative of momentum
   e. Uniform circular motion and gravitation
   f. Work as the integral of force
   g. Area under the curve and the Reimann sum
   h. Work and energy
4. Electrostatics
   a. Coulomb forces
   b. Electrical potential and voltage
5. Vibrations and waves
   a. Springs and mass
   b. Mechanical waves
   c. EM waves (micro and light)

6. Atomic Structure
    a. Bohr model
    b. The periodic table

Computer Equipment and Experiments

With financial support from the National Science Foundation and guidance from the TYC workshops, we purchased eight Power Macintosh computers, Vernier's MBL equipment and Pasco's Carts and Tracks. These incorporate Vernier software and hardware with Thornton's "Tools for Scientific Thinking". Last semester we utilized Mathematica, Mathcad and Excel software.

Computers are utilized for Euler's method, variations of parameters, graphing, and MBL-based laboratory experiments as developed by Thornton and Laws. Data collection, error analysis and report writing skills are emphasized.

Timeline
Semester I

calculus	physics	joint presentations	weeks
precalculus review	optics - Law of Reflection, Snell's Law		1 and 2
limits	optics - thin lenses	the Thin Lens Equation and limits	3 and 4
the derivative	position, velocity, and acceleration functions	graphs of position, velocity, and acceleration functions using MBL's and their derivative relationships	5- 5.5
techniques of differentiation	1D kinematics	derivation of the velocity and acceleration functions given a position function (constant acceleration)	5.5 - 6.5
differentials	experimental uncertainty	using differentials in uncertainty analysis	6.5 - 7
Euler's method	free-fall	using Euler's method to approximate the position function given an experimental value of the acceleration due to gravity	7 - 7.5
related rates	2D kinematics	position, velocity, acceleration, and related rates	7.5 - 8
graphing functions	introduction to Newtonian Mechanics		8 - 8.5
optimization	free body diagrams	minimum force problems	8.5 - 9
Mean Value Theorem			9 - 9.5

antiderivatives & introduction to differential equations	force due to a spring	velocity and position functions given a variable force	9.5 - 10
area under a curve	rotational motion	displacement as area under a velocity curve	10 - 10.5
Riemann sums		approximating gravitational force due to a rod of uniform linear density	10.5 - 11
the definite integral	work/energy		11 - 11.5
First Fundamental Theorem of Calculus		work done by a spring	11.5 - 12
integration by substitution		approximating gravitational force due to a rod of uniform linear density	12 - 12.5
area between curves	electrostatic force	electrostatic force due to a rod of uniform charge density	12.5 - 13.5
average value of a function - Mean Value Theorem for Integrals - Second Fundamental Theorem	electric fields	electric field of an infinite wire	13.5 - 14
logarithmic and exponential Functions	RC circuits	charge on a capacitor	14
	introduction to magnetism	magnetic field of an infinite wire	15
polar coordinates - areas in polar coordinates			16

SIPSE'S SEMESTER II:
ENGINEERING PHYSICS I AND CALCULUS III

Calculus and physics topics are closely interwoven in SIPSE's Semester I; however, they are even more closely interwoven in Semester II. Thus, Semester II's description is not divided into a calculus course description and a physics course description. Rather, it is divided into four parts: lectures, joint presentations, labs, and study group activities.

LECTURES

In Semester I, the order of the calculus topics determines the order of the physics topics. In Semester II, the physics order usually determines the calculus order. The physics order is, for the most part, the same as that of the text, Physics, 4th edition, by Resnick, Halliday, & Krane (H&R). There are two major exceptions to this. The chapters on fluid statics and dynamics (Chap. 17 & 18) are moved to the beginning of the course, just after the chapters on measurement (Chap. 1) and motion in one dimension (Chap. 2.), giving the math teacher time to cover vector algebra and to introduce vector calculus before it was needed in physics. In doing so he exhausted most of the material found in H&R Chapters 3 and 4, vectors and two and three dimensional motion, so only an abbreviated version of these topics was presented in physics. This elimination of the double coverage of material freed up more than two weeks of physics lecture time.

The math portion of the course used two texts (at different times): Anton's Calculus and Larson's Calculus. The math lecture topics are sequenced to meet the needs of the physics part of the course, so the order is quite different from that found in either of the two texts. In particular: the sections on planes and quadric surfaces are delayed until the conclusion of 3D motion; the section on cylindrical and spherical coordinates is delayed until it is needed in triple integrals; the sections on line integrals and path independence are covered early (they follow the section on the gradient); the sections on optimization are delayed until the conclusion of multiple integrals. This sequencing would be a jumbled mess in a stand-alone course; it works quite nicely in our combined course.

The Anton and the Larson texts were easily adapted to this new order. We investigated using the Harvard Reformed Calculus text, but found that it would not allow students to take calculus in the order I-III-II; too much of the material traditionally covered in Calculus I is covered in Calculus II.

The teaching of the traditional engineering physics course is usually limited by students' lack of appropriate mathematical background and

insufficient time during the course to impart the background. Consequently, an abbreviated version of the needed math is taught by the physics teacher. This is sometimes at odds with what the students learn later in math, as will be seen below. In SIPSE, every math concept needed is explored in depth, rigorously, intuitively, and on time. A characteristic of the physics presentation is the intensive use of math. The two subjects are seamlessly joined through team teaching and formal joint presentations, leaving the student with the impression that all was one.

JOINT PRESENTATIONS

The joint presentations are attempts to clarify contradictory and confounding concepts, as well as elucidate some in great depth. Some of the presentation material has not, to our knowledge, appeared anywhere in elementary form. This material, mainly concerning div, grad, and curl, is briefly described later in this document and will be available in booklet form from J. Ardini at the end of the Fall 96 semester. Formal joint presentations are in addition to the normal, almost daily, give and take among the instructors and the students that gives a seminar-like flavor to the lectures and joint presentations..

STUDY GROUPS

The instructor-supervised study group exercises were designed to expand and solidify student understanding of the math used in physics. These groups are led by tutors who have previously done the exercises and who are in possession of detailed solutions. These groups produce a much deeper understanding of the academic points made, as well as a camaraderie and friendship among the students that, for many, persists at transfer institutions. The study group meetings are pervaded by a seminar atmosphere, with many an argument surfacing and many a challenge issued. It was during these times that the instructors are most challenged, settling issues or being forced to bring back answers. Though this collaborative learning is a boon to students, it also had a down side. The instructor had to ensure that the blind don't lead the blind—we found on several occasions that incorrect interpretations of concepts were being passed around. A list of the study group exercises is given later in this document.

LABS

Our labs are quite different from the traditional Physics I labs. Their purpose is to do more than confirm the principles presented in the lecture, they are also used to teach the application of vector and multivariable calculus, as well as statistical data reduction, to physics. Thus, each lab has two components: the confirmation of the physical principle and the

application of a complementary mathematical principle. The titles of the labs don't always reflect this, but the stated purposes of each lab do.

Before each lab there is a discussion of the principles involved and a number of pertinent problems are solved. Also, each student has to produce a professional quality report that is closely corrected, including grammar and spelling. The students use word processors, spreadsheets and calculators to analyze the data and write up the lab. Some labs require some elementary programming, which is done with whatever language the student finds most convenient (primarily BASIC, FORTRAN, Pascal, and C). The students that have no programming experience work closely with the faculty and the student tutors.

Most labs span two weeks and a few extend to three weeks. The first session of each lab included a presentation of the theory of the lab including the mathematics involved, the possible measurements needed, the problem of uncertainty, and, in the initial labs, what is expected in the report. Usually data is collected in the first lab session. The next lab session is spent analyzing data, checking suspicious data and calculations, and readying the report. Students are given a report writing guide and are informed that the report would be judged as if it had been submitted to an employer. In preparing their preliminary write-ups, many students realize that they have serious gaps in their understanding and seek help. Writing seemed to clarify the problem. Many of the final write-ups were close to publishable quality (after the first few had been soundly criticized).

The number and content of labs vary from semester to semester. All of our labs are listed in the following timeline; a subset of five to seven is given each semester.

TESTING

In the physics portion of the course, two midterms, a final, and about ten quizzes are given. In the math portion, two midterms, a final, and about 12 quizzes are given. The midterms and the finals are designed for two hours, but students are given three hours to complete them. The students receive two separate grades, 1 in math and 1 in physics, due to our transfer agreements with four year schools.

We found that testing brings students face to face with their ignorance, and during this time they are most intensively involved with the subject matter. Therefore, the exams are designed to give them plenty of time to experiment with approaches. Physics practice exams with solutions from

previous classes are distributed to help in their preparation. Physics is a new subject to the students, and practice exams help them determine what is expected of them. Math practice exams are not distributed.

Timeline

In the following timeline, the course is segmented into sections A through F, each of which contains lecture, lab, and joint presentation topics. The timeline is followed by a detailed discussion of sections A through F.

ENGINEERING PHYSICS I		CALCULUS III
	A	
Introduction history & scientific modeling ratio & proportion dimensional analysis Kinematics (1D) acceleration to position via integration analysis of graphs		Vector Algebra i, j, k and <1,1,1> notations cross & dot products projections

LAB: Pendulum: log-log plots, finding g
LAB: 3D Equilibrium: directional angles & cosines

Joint Presentation: Simple Differential Equations

	B	
Fluid Statics & Dynamics density, pressure, Archimedes', Pascal's, Bernoulli's principles, continuity eq., streamlines & fields Kinematics (2&3D) position through acceleration uniform circular motion		Vector Valued Functions derivatives & integrals $a = a_T T + a_N N$ T, N, B frame *MATH MIDTERM*

LAB: Reaction times; distributions and characteristics (normal and others)
LAB: Presentation of propagation of uncertainty: sig figs vs. differential & statistical propagation
LAB: Area calculation comparing uncertainty propagation using sig figs, differentials, and standard deviation

Joint Presentation: 3D motion: $\mathbf{u_r}$ & $\mathbf{u_\theta}$ Vs T, N, & B.

C

Newton's Laws of Motion
  2nd law - definition or law?
Inertial & Non-inertial Systems
  centrifugal & centripetal forces
  friction

Partial Derivatives
  tangent planes
  directional derivatives
  gradient

LAB: Writing a computer program using Euler's method to model projectile motion (also other forces)

PHYSICS MIDTERM

Work & Kinetic Energy
Potential Energy
  conservative & nonc. fields

Line Integrals
  work & circulation
  path independence & conservatism

Joint Presentation: Line integrals, conservative fields, and the gradient.

D

Centers of Mass & Gravity
  conservation of linear momentum
Collisions
  impulse, momentum, 2D collisions
  CM reference frame
  using single Vs multiple integrals to get C.M.

Multiple Integrals
  centers of mass & gravity

LAB: Conservation of momentum (air table)
LAB: Center of mass: measuring and calculating centers of mass

Joint Presentation: Center of Mass and elementary distribution functions

E

Rotational Kinematics and Dynamics
  vector quantities (linear/rotational)
  rotational equations compared with
    linear equations
  precession
Cons. of Angular Momentum
Equilibrium
  statics problems

Optimization
  Lagrange multipliers

MATH MIDTERM

PHYSICS MIDTERM

Gravitation
  inverse square fields
  gravitational potential energy
  planetary motion (Kepler)
  lines of force into lines of flux
  Gauss's law for gravitation

Divergence & Curl
  Green's Theorem
  Gauss' Theorem
  Stokes' Theorem

Joint Presentation: Conservative & non-Conservative Fields (cont'd.), physical interpretations of divergence and curl

LAB: Behr Free Fall and data reduction: revisiting the pendulum lab for data reduction

F

Oscillations
Hooke's Law & SHM

Joint Presentation: Introduction to Taylor Series, Euler's Formula

LAB: Power series, Taylor series, expansion of sines, cosines, and $e^{i\theta}$. Also an intro to Fourier series
LAB: Damped Harmonic Oscillations: mass on spring with aluminum strip in magnetic field

Traveling Waves
wave equation & sound

LAB: Standing Waves in Wire: driven by current through wire in magnetic field.

Section A

Lecture:
While the math instructor uses the majority of the time to cover vector algebra, the physics instructor augments the math instructor's lectures and reviews 1D kinematics. Calculus texts treat motion by starting with displacement as a function of time and then differentiating to obtain velocity and acceleration. We emphasize the reverse process, first giving students the force law or acceleration and then integrating to obtain velocity and displacement. This introduction to elementary differential equations had important pedagogical ramifications throughout the rest of the physics course.

We continue Semester I's emphasis on the differential. We show students how to view a derivative as a ratio of differentials that in turn can be viewed as a ratio of infinitely small differences.

Lab:
1) Pendulum: Students find the acceleration due to gravity by estimating a linear fit of period versus length on a log-log plot. Later the data from this lab is regressed on a calculator.
2) Static Equilibrium: Students solve a 3-D equilibrium problem to see if $\Sigma F = 0$. They suspend three masses from pulleys to counterbalance the weight of a central mass, and make direct measurements of distances from

which they calculate direction cosines and angles. They place these into a system of equations and find the force on the central body. They compare this magnitude with that of the weight of the central body.

Joint Presentation:
Simple Differential Equations: We show students how to write simple difference equations to model various simple physical situations, such as radioactive decay. (The lab discussed below in Section C used difference equations and Euler's method to model projectile motion.) The students turn the difference equations into differential equations, separate the variables, and integrate the results.

Section B

Lecture:
While the math instructor covers the basics of vector calculus, the physics instructor covers fluid statics and dynamics. Both instructors cover 2-D and 3-D motion, the math instructor using the T, N, and B unit vectors commonly used in math and the physics instructor using the u_θ and u_r unit vectors commonly used in physics. As in Section A, multiple coverage is eliminated. Though there was a considerable savings in time, the students exhibit an increase in clarity and depth of understanding as demonstrated by their ability to solve problems.

Lab:
3) Reaction Time: The students determine if individual and class reaction times are normally distributed. One student drops a ruler and the other catches it between thumb and index finger. They use the distance dropped to calculate time. We discuss the normal distribution, as well as the mean, mode, and the standard deviation.
4) Uncertainty: We discuss rules for the use of significant figures (sig figs) in uncertainty propagation, and the use of sig figs in determining the uncertainty of physical constants found in standard lists. We compare the use of sig figs to the use of the differential and the standard deviation in analyzing uncertainty.
5) Area and Propagation of Uncertainty: The students measure the dimensions of irregular shapes and calculate uncertainty propagation using sig figs, differentials, and standard deviations.

Joint Presentation:
2) 3D motion: u_r & u_θ Vs T, N & B. We compare and contrast these base vectors, using both circular motion and non-circular motion. We point out that the bases u_r and u_θ are tied to a coordinate system while T, N, & B are tied to the position of the object.

Section C

Lecture:

The remainder of the physics portion of the course follows the sequence of topics in H&R. However, because the math teacher is able to tailor the math to the needs of physics, almost all topics in physics are taught with greater mathematical depth than usual. For example, his coverage of directional derivatives, partial derivatives, and gradients allows an in-depth treatment of least square fits as well as the use of the total differential in uncertainty propagation. His coverage of line integrals and path independence occurs in time for the physics teacher to cover work and potential energy and eliminates the need and time to teach about the line integral in physics.

We discuss force fields in which the work done between two points is dependent on the path, and some in which the work is independent of path. We connect path independence to the existence of scalar potential energy. Thus, we clearly illustrate the difference between a conservative and a non-conservative field. We use the directional derivative to get force components in any desired direction from graphs of equipotential lines and from potential energy functions, emphasizing that the x and y-components of force are the negative partial derivatives of the potential energy. We explain the difference between math's potential function and physics' potential energy function.

Lab:

6) Projectile Motion: The students write a computer program using Euler's method to predict path. They also write programs involving non-constant forces such as gravitation and Hooke's law.

Joint Presentation:

3) Conservative Vector Fields: We compare and contrast the math parametric approach to the line integral with the physics non-parametric approach. We discuss the different uses of the parameter t; in math t is an arbitrary parameter but in physics it is always time. This pedagogical impediment often confuses students.

We connect the physics version of a conservative field, which emphasizes path independence, with the math version of a conservative field, which emphasizes irrotationality and gradient fields. We connect exact and inexact differentials to conservatism. Also, we contrast math's potential function Φ, where $\vec{F} = \nabla\Phi$, with physics' potential energy U, where

$\vec{F} = -\nabla U$. This difference is not usually addressed in the regular physics or math courses, leaving students with a confused idea of potential.

In this presentation many strands of physics and math are drawn tight. These ideas are clarified by the exercises given to the study groups, and are revisited in more detail later in the course.

Section D

Lecture and Joint Presentation:
Center of mass, linear momentum, and impulse are next. At this level of physics centers of mass are calculated with single integrals. However, the math texts calculate centers of mass with multiple integrals. We present both methods. At first students find the multiple integral approach to be simpler than the single integral approach. After a joint presentation in which a number of such problems are solved with both methods, they see that old integrations can be recycled without re-integrating them if the symmetry is right. Students are allowed to use either method, but we are certain to assign some more challenging problems that require multiple integration, and some that are more easily done with single integration. We also use this presentation to revisit the mean, mode, and variance of distribution functions.

Lab:
7) Conservation of Momentum: Air tables and two dimensional vectors.
8) Center of Mass: Students compare the theoretically calculated center of mass of 2-D objects (flat plastic sheets, some with holes) and 3-D objects (cones made from FIXALL cast into party hats) to the experimentally determined center.

Section E

Lecture:
While the physics instructor covers rotational kinematics and dynamics and simple statics, the math instructor covers optimization. The physics instructor augments this with a preview of the Lagrangian and Hamiltonian physics that the students will encounter in their upper division work.

While the math instructor covers divergence, curl, Gauss', Green's and Stokes' theorems, the physics instructor defines specific force, i.e., field strength, for the gravitational, electric, and magnetic fields, g, E, and B. (B is defined as force per pole, instead of the usual way used in the standard textbooks.) Here, lines of force, later, lines of flux, are introduced as a way

of visualizing a field. We point out that it is natural to expect that the total number of lines would be proportional to the quantity of material producing them, e.g., charge and mass, and that the number of the lines per unit area would be proportional to the field strength, and, in fact, set equal to the field strength. This allows the students to calculate the number of lines passing through a surface using surface integrals and sets the stage for the integral form of Gauss' law. Also, we revisit specific potential energy, i.e., potential energy per unit quantity, called simply 'potential' in physics, using the gravitation field U/m, and the electric field for a point charge, V = U/q., again emphasizing the difference between the potential function as defined in math and the potential and potential energy functions as defined in physics.

The integral form of Gauss' law for gravitation is covered in detail and g is calculated using several simple symmetries. The law is extended by analogy to the electrical and magnetic cases. Divergence as the limit at a point of the net flux lines passing from a closed surface per unit volume around the point is viewed as a volume flux density and related to and used in the same fashion as volume density. It is a natural step to calculate the number of lines leaving a surface as either the surface integral of the field strength over the closed volume or as the volume integral of the divergence. This intuitive view of Gauss' law permits problems to be assigned as precursors to the integral and differential forms of two of Maxwell's equations, including the gravitational analogs, which are presented soon after. Also, since the gradient is available, we present Poisson's and Laplace's equations. Laplace's equation is used to solve for the potential between two parallel infinite plates. We feel it is important that they are exposed to the differential forms of Maxwell's laws since they were ready for them, even though popular lower division physics texts do not treat them.

One of the most difficult concepts for students is that of the curl, and its physical meaning. After the almost strictly mathematical introduction by the math teacher, the physics teacher tackles the physical meaning of the curl starting with the one, and usually only one, interpretation commonly used, i.e., the curl of a velocity field associated with a rotating solid object is 2ω. Another approach is then used to give a much better physical meaning to the curl of force, momentum, and acceleration fields. The circulation of each of the field strengths, g, E, and B, is shown to be work per cycle per mass, charge, or pole. The curl is then restrictively defined as the limit of the circulation per area, picking a field in which direction could easily be assigned. The vector nature of curl is discussed and, with more complex fields, the magnitude of its components in other directions

are discussed. The curl of a force field is then used to get the increase of kinetic energy of a particle during one turn while constrained inside a frictionless loop of tubing conveniently situation in the field. A general discussion follows about using curl to identify conservative fields and exact and inexact differentials. With this preparation the students are able to complete many curl related problems in the study groups.

Lab:

9) Free Fall: The students use Behr free fall apparatus and analyze the data with quadratic regression. We derive equations for linear, cubic, and higher degree regressions. We contrast regression of y on x with regression of x on y. We demonstrate how to use the TI and HP calculators for regression.

Joint Presentation:

5) Conservative & Non-Conservative Fields (cont'd.)

We discuss interpreting curl as work per area per turn as well as the use of curl to determine if a force field is conservative. We use Ampere's law applied to a current carrying wire to show that the curl of B at points outside the wire is zero. Assuming a constant current density in the wire, it is easy to get the curl in the wire. We show that the B field around the wire is globally non-conservative, but locally conservative in a subspace outside the wire. We revisit fluids and discuss streamlines as flux lines.

Section F

Lecture:

Vibrations, at the lower division level, are usually analyzed with real-valued functions. This leaves students with only a vague idea of what angular frequency represents. We introduce Euler's formula by way of Taylor series, and also the rotating complex vector, $e^{i\theta}$. In a single lab period the students are able to move to a whole new plateau of understanding, especially of angular frequency, unavailable to students in the other sections of Engineering Physics I. This use of the complex exponential makes the treatment of damped and forced damped harmonic motion much easier. It also makes it easier to view the superposition of waves. Many students are delighted that they can now get the logs of negative and complex numbers, as well as easily find the trig identities involving the sums and differences of angles.

Lab:

10) Presentation lab: Power series, Taylor series, expansion of sine, cosine, and e^{ax}. The unit vector $e^{i\theta}$ is studied with $\theta = \omega t$, ω constant

11) Damped Harmonic Oscillations: A mass on a spring has an aluminum strip attached that is suspended between the poles of a magnet to provide damping. The solution is found using complex functions.
12) Standing waves in Wire: Wire in a magnetic field is driven by a current.

Joint Presentation:
6) Introduction to Taylor Series & Euler's Formula: Taylor Series are introduced, and Euler's formula is found using Taylor series. This is done again in more detail in a lab presentation. The complex solutions to Hooke's law (damped and undamped) and the wave equation are shown. Also, some trig identities are found using Euler's formula, and logs of negative and complex numbers are found.

Physics Group Study Exercises

The physics group study exercises tend to be dissimilar to the exercises in the text, due to the emphasis on the application of calculus and statistics to physics. Some of these extend to two weeks. The students work together, but each student submits individual solutions. In the math study groups, each group submits one solution set.
1) Solve simple differential equations (separation of variables). In particular various accelerations as functions of time are given and velocity and displacement are found.
2) Units systems. Derive relationships using dimensional analysis. Unit conversions.
3) Distribution functions, mean, mode, standard deviation, standard deviation of means.
4) Uncertainty propagation: significant figures, propagation using differentials, propagation of standard deviation.
5) Static equilibrium problems.
6) Directional derivatives, partial derivatives and gradient.
7) Linear and quadratic regression.
8) Rotational dynamics problems.
9) Line integrals - work done in various force fields. Potential energy found where possible with emphasis on inverse square field and Hooke's law.
10) Calculations involving curl. Divergent problems were done during lecture.
11) Center of mass of various objects, both 2-D and 3-D.
12) Set up difference equations and turn them into differential equations, e.g., growth and decay problems (radioactive decay, radiation attenuation, C.M., moment of inertia, distribution means and mean squares). Solve the diff. eqs. This exercise revisits group exercise #1.

APPENDIX III

NOTATIONAL, TERMINOLOGICAL AND STYLISTIC DIFFERENCES BETWEEN MATHEMATICS AND PHYSICS

In the following discussion, the mathematics notation is followed by the corresponding physics notation. Faculty easily understand the equivalence of these differing notations; students do not always understand this equivalence.

$3\vec{i} + 2\vec{j}$ or $<3, 2>$ *versus* $3\hat{x} + 2\hat{y}$

Vector notation can be quite similar; a mathematician might write $3\vec{i}$ where a physicist would write $3\hat{i}$. However, the <3, 2> notation is commonplace in lower division mathematics, while it doesn't appear in physics until upper division work. Furthermore, math and physics texts tend to avoid either of these notations in favor of the use of boldface to indicate vector quantities. Thus, a student could well see:

- <3, 2> in his math class
- $3\hat{x} + 2\hat{y}$ in his physics class
- 3i + 2j in his math text
- 3x + 2y in his physics text

without any indication that these are synonyms.

$\|\vec{v}\|$ *versus* v

Mathematicians use the norm operator to describe the norm of a vector, while physicists write the norm of a vector $\vec{v}$ as the scalar v. The mathematicians' norm operator is more cumbersome than the physicists' deletion of the vector arrow. However, the norm operator allows the mathematician to distinguish between $\frac{d}{dt}\|\vec{r}\|$ and $\left\|\frac{d\vec{r}}{dt}\right\|$, while the physicist must write $\frac{dr}{dt}$ for both.

$\frac{\vec{v}}{\|\vec{v}\|}$ *versus* $\hat{v}$

Mathematicians don't have a simple, consise notation for a unit vector. This notation should be universal.

$\int_C \vec{F} \bullet d\vec{r}$ *versus* $\int_C \vec{F} \bullet d\vec{s}$ *or* $\int_C \vec{F} \bullet d\vec{l}$

Mathematicians' integrate line integrals with respect to the position vector

$\vec{r}$, where physicists integrate with respect to the arc length vector $\vec{s}$ or $\vec{l}$. While $d\vec{r}$ and $d\vec{s}$ are essentially the same, their definitions are not similar. Calculus texts define $d\vec{r}$ as $\frac{d\vec{r}}{dt}dt$; physics texts define $d\vec{s}$ as a vector whose magnitude is ds and whose direction is tangent to the curve. Thus, the physicists' $d\vec{s}$ is actually equivalent to the mathematicians' $\vec{T}ds$.

$\iiint f(x,y,z)dV$ versus $\int f(x,y,z)dV$
Frequently, a physicist writes a single integral where a mathematician writes a double or triple integral. Physicists use an integral symbol to mean the general concept of integration, where mathematicians use one integration symbol for each dimension.

$\vec{n}dS$ versus $d\vec{S}$
Mathematicians make vectors out of scalars by combining the appropriate scalar (dS) with a unit vector in the appropriate direction ($\vec{n}$). (The unit vector is merely understood to be a unit vector, since mathematicians lack the "hat" symbol.) Physicists tend to make vectors out of scalars by inserting a vector arrow over the scalar ($d\vec{S}$). Another example of this is the mathematicians' $\vec{T}ds$ and the physicists' $d\vec{s}$ discussed above.

div $\vec{F}$ *versus* $\nabla \cdot \vec{F}$
curl $\vec{F}$ *versus* $\nabla \times \vec{F}$
Some texts refer to both notations, and some don't.

Φ *versus* U
In mathematics texts, Φ is the potential function of $\vec{F}$ if $\nabla\Phi = \vec{F}$.
In physics texts, U is the potential energy of $\vec{F}$ if $-\nabla U = \vec{F}$.
These similar-but-different notations and terminologys are truly unfortunate.

the parameter t
In physics texts, t is always time. In mathematics texts, t is usually an arbitrary parameter, but sometimes it is time. This different use of the letter t can be especially troublesome when computing the work done by a force $\vec{F}$ in moving an object along a path given by the position function $\vec{r}(t)$. If t is *not* time, then the work done is

$$\int_a^b \vec{F}(\vec{r}(t)) \cdot \frac{d\vec{r}}{dt}\,dt$$

However, if t *is* time, then $\frac{d^2\vec{r}}{dt^2}$ is acceleration, a new force has been introduced, and the above line integral is not equivalent to the work done by a force $\vec{F}$.

spherical coordinates
Mathematicians describe a point in three space with the ordered triple (ρ, θ, ϕ) where ρ denotes the distance from the origin to the point, θ denotes the angle between the projection of the point into the xy plane and the positive x axis, and ϕ denotes the angle between the point and the positive z axis. Often, physicists use r where mathematicians use ρ (they use ρ for density), ϕ where mathematicians use θ, and θ where mathematicians use ϕ.

the x subscript
Mathematicians frequently use the x subscript to denote a partial derivative with respect to x. Physicists always use it to denote the x component of a vector.

Mathematics and physics faculty could eliminate the difficulties that these notational and terminological differences impose on students by utilizing both sets of notations and terminologys. It is inappropriate for a mathematics instructor to use only the math notations, because this decreases a student's ability to understand the commonalities between mathematics and physics. It is also inappropriate for a mathematics instructor to use only the physics notations, because the student must be able to learn in both the mathematics and the physics worlds.

In addition to notational differences, there are other important differences that can hinder the student.

computing a dot product
Mathematicians compute dot products with a formula:
$\langle 1,2\rangle \cdot \langle 3,4\rangle = (1)(3) + (2)(4)$
Physicists compute dot products with the distributive property and the property that the dot product of two orthogonal vectors is 0:

$$\begin{aligned}(1\hat{i} + 2\hat{j})\cdot(3\hat{i} + 4\hat{j}) &= (1)(3)(\hat{i}\cdot\hat{i}) + (1)(4)(\hat{i}\cdot\hat{j}) + (2)(3)(\hat{i}\cdot\hat{j}) + (2)(4)(\hat{j}\cdot\hat{j}) \\ &= (3)(1) + (4)(0) + (6)(0) + (8)(1)\end{aligned}$$

computing a line integral
Mathematicians use parametric methods to compute line integrals. That is, if $\vec{r}(t)$ is the position function corresponding to a curve C, then

$$\int_C \vec{F}\cdot d\vec{r} = \int_a^b \vec{F}(\vec{r}(t))\cdot\frac{d\vec{r}}{dt}\,dt$$

At the lower division level, physicists avoid parametric methods. If θ is the angle between $\vec{F}$ and $\vec{T}$, then

$$\int_C \vec{F}\cdot d\vec{r} = \int_C F\cos\theta\, dr$$

In the problems that come up, much of the integrand is a constant and the resulting integral is quite simple. Mathematics instructors should consider covering both approaches.

the differential

Physicists use the differential as much as the derivative. Some calculus texts never mention the differential. When it is mentioned, it is defined in terms of the derivative and used only in the analysis of uncertainty.

Riemann sum arguments versus infinitesimal arguments

Mathematicians use Riemann sum arguments when justifying the application of an integral. For example, when discussing the work along a curve C, a mathematician will approximate the work along a small subset of C by dotting $\vec{F}$ with the displacement vector $\vec{r}(t+\Delta t)-\vec{r}(t)$. The work along C is then the limit of the sum of these dot products.

In these same situations, physicists use infinitesimal arguments. A physicist will calculate work by dotting $\vec{F}$ with the infinitesimal arc length vector $d\vec{s}$ and summing the results by integrating.

$\vec{T}, \vec{N}$ and $\vec{B}$ versus $\widehat{\mathbf{u}_r}$ and $\widehat{\mathbf{u}_\theta}$

Calculus texts use $\vec{T}, \vec{N}$ and $\vec{B}$ to analyze motion. Lower division physics texts use $\widehat{\mathbf{u}_r}$ and $\widehat{\mathbf{u}_\theta}$. Math texts should discuss both approaches. Also, the students would benefit from having these two sets of base vectors compared and contrasted.

The mathematical approach and notation are often congruent with those of physics. However, there are also incongruences, and the student is never told about them. The relative frequency of the congruences allows the student to believe that the two sciences use the same language; in fact they use different dialects that involve both subtle and gross differences. This leads to unnecessary confusion on the part of the student. Much of this confusion would be eliminated if math faculty made regular use of physics notation and terminology, and vice versa; this could easily be done in a traditional stand-alone class. The confusion that arises due to differences in style and approach are more difficult to handle, unless a mathematician

and a physicist are team teaching.

APPENDIX IV

Dr. Eve Kelemen's independent evaluation follows.

FINAL ANALYSIS FIPSE GRANT

DIABLO VALLEY COLLEGE

INTERDISCIPLINARY MATH-PHYSICS PROGRAM

The final analysis for the FIPSE Interdisciplinary Math-Physics program consists of four major parts. The first three of these consist of quantitative data and the last enlists qualitative evaluations. These are: 1. a table listing the success rates and withdrawal rates for the experimental compared to the control groups; 2. a comparison of the grades between the interdisciplinary students and students taking math and physics separately in the traditional manner; 3. an analysis of the ratings the students in the two groups of classes gave to the courses in the Anonymous Questionnaire; and 4. an overview of the comments made by the students on the Anonymous Questionnaire. These four types of analyses give a well-rounded view of the program; two are completely objective, based on the students' grades; the third is subjective as it is the students' opinions; and the fourth reflects the affective component.

I. Success Rates and Withdrawal Rates for the Experimental (Interdisciplinary Students) Compared to the Control Group (students taking their math and physics courses separately)

Four courses were involved in this program, the two beginning math and physics courses, Math 192 and Physics 129, and the two succeeding math and physics courses, Math 292 and Physics 130. The success rate was determined by combining the number of students receiving A's, B's and C's and dividing by the total number of students in the course. The result was then multiplied times 100 to form a percentage. Similarly, for the withdrawal rate, the number of students withdrawing from the class was divided by the total number of students in the class. This decimal was then multiplied times 100 to form a percentage. Inter. stands for the Interdisciplinary Math-Physics courses and Trad. represents the Traditional courses which were used as the control group.

YEAR	SEMESTER	COURSE	INTER. SUCCESS RATE	TRAD. SUCCESS RATE	INTER. WITH-DRAW RATE	TRAD. WITH-DRAW RATE
			SUCCESS AND WITHDRAWAL RATES ARE IN PERCENTS			
1991	Spring	Physics 110	87.5	65	12.5	25
1993	Spring	Physics 129	72	56	17	22
1994	Fall	Physics 129	78	65	15	24
1995	Spring	Physics 129	67	76	9	24
1996	Spring	Physics 129	76	68	24	24
Total		Physics 129	76	65	15	25
1990	Fall	Math 192	62.5	56	19	34
1993	Spring	Math 192	68	58	10	33
1994	Fall	Math 192	69	63	15	23
1995	Spring	Math 192	57	55	14	31
1996	Spring	Math 192	68	63	23	25
Total		Math 192	66	60	16	29
1991	Spring	Physics 130	100	53	0	32
1993	Fall	Physics 130	83	53	13	33
1994	Fall	Physics 130	87.5	57	0	36
1995	Spring	Physics 130	83	74	4	16
1996	Spring	Physics 130	73	65	23	28
Total		Physics 130	83	60	9	29
1991	Spring	Math 292	89	65	11	32
1993	Fall	Math 292	60	59	13	27
1994	Fall	Math 292	80	68	4	16
1995	Spring	Math 292	79	80	4	12
1996	Spring	Math 292	62	53	24	35
Total		Math 292	72	66	11	24

As can be seen from reviewing this table, success rates were consistently higher and withdrawal rates consistently lower for the interdisciplinary courses than for the courses taught in the traditional manner. Even when the differences in success rates were small, the withdrawal rate differences were large. Frequently students who withdraw do so due to poor grades. Therefore, if these students had completed the course it could be expected that the differences in success rates would have been larger.

II. A Comparison of the Grades Between the Interdisciplinary Students and a Control Group

Two statistical analyses were performed on the grades of the Interdisciplinary students and a Control group. As reported previously, the Control students actually had superior skills, as measured by the MDTP tests, to the Interdisciplinary students. The MDTP tests are norm referenced math placement tests developed at the University of California. This is to be expected, since the Interdisciplinary group was selected as students less likely to succeed in math and physics classes who were being encouraged to try this program.

The analyses that were conducted were a t-test and a chi-square test. A t-test is a parametric test which is most powerful when the groups are of equal size. If this is not the case, then it is important that the assumptions of homogeneity of variance and a normal distribution are met. The chi-square test is a non-parametric test which does not require that the above assumptions be met. If the t-test is significant, there is assumed to be a difference between the means of the two sets of scores, with the scores of the experimental group (Interdisciplinary students) being higher than those of the control group (Traditional students). If the chi-square test is significant, the distributions of the sets of scores are assumed to be different. In this case, it would reflect a greater number of higher grades among the Interdisciplinary students. An alpha level of .05 is used to determine significance.

RESULTS OF T-TESTS AND CHI-SQUARE TESTS FOR PHYSICS 129, MATH 192, PHYSICS 130 AND MATH 292 FOR ALL YEARS COMBINED FOR FINAL GRADES

COURSE	t - TEST RESULTS	CHI-SQUARE RESULTS
PHYSICS 129	p = .003 significant	p = .000 significant
MATH 192	p = .30 not significant	p = .08 not significant
PHYSICS 130	p = .000 significant	p = .000 significant
MATH 292	p = .05 significant	p = .001 significant

The results are significant at the .05 level for all courses except Math 192 with the grades being higher for the Interdisciplinary courses on the t-test and the grade distribution showing more higher grades for the Interdisciplinary courses on the chi-square analysis. However, it should be noted that the students taking Math 192 were also taking Physics 129. Though their grades may not have been significantly better in the math course, it did improve their ability to succeed in physics.

III. An Analysis of the Ratings in the Anonymous Questionnaire

At the end of the courses being studied, students were given an Anonymous Questionnaire to determine how they rated the course. Certain questions could not be asked of the control group, but comparisons were made on questions that were similar between the two groups. These were:

2. Did your study habits change as a result of your participation in this class?

3. Did your commitment to your major change as a result of your participation in this class?

4. Did the amount of time you devote to math and physics (or math or physics) change as a result of your participation in this class?

5. Were study groups of value to you?

6. Please evaluate the physics portion of this semester's program.

At this time, only the physics portion of the Interdisciplinary courses is being evaluated due to the fact that control group data is available only from physics courses. Another similar question, to evaluate the math portion, will be analyzed once data is available from math courses.

Both t-tests and chi-square tests were used for this comparison. As explained above, a significant result on each of those tests implies something different. The t-test is a parametric test of the difference between the means of the two groups, whereas the chi-square test examines the difference between the distribution of scores. All questions were rated on a 5 point scale. An alpha level of .05 was used to determine significance.

RESULTS OF T-TESTS AND CHI-SQUARE TESTS FOR PHYSICS 129, MATH 192, PHYSICS 130 AND MATH 292 FOR ALL YEARS COMBINED FOR RATINGS ON THE ANONYMOUS QUESTIONNAIRE

QUESTION	t - TEST RESULTS	CHI-SQUARE RESULTS
2. Study habits change	p = .019 significant	p = .028 significant
3. Commitment to major change	p = .43 not significant	p = .67 not significant
4. Amount of time studying change	p = .000 significant	p = .005 significant
5. Were study groups of value	p = .03 significant	p = .124 not significant
6. Evaluate physics portion	p = .32 not significant	p = .23 not significant

It is clear that as a result of taking the Interdisciplinary courses, students improved their study habits and the time they spent studying (all significant results are in the direction of higher ratings for the Interdisciplinary courses). This may be the reason that their overall grades are significantly better than the students in the Traditional courses. The overall ratings of the classes are difficult to interpret since the students had nothing to compare to. The students taking the traditional classes had no idea what the interdisciplinary courses would have been like. Therefore, the ratings were

high. In addition, teachers were trying some of the techniques they had developed in the Interdisciplinary courses, such as study groups, in the traditional courses.

IV. An Overview of the Student Comments on the Anonymous Questionnaire

Student comments varied considerably, though generally the students in the Interdisciplinary courses became more committed to being students and engineers as a result of being in the program:

I'm more dedicated to my homework and working on it makes me picture myself with a future in engineering.

Yes, the program did change my study habits. It made me spend more time on my homework than I did last semester.

This class definitely changed my study habits for the better. They helped me prepare better for the college years yet to come.

Before the program I had no organized study habits and they were last minute as well. Now I have wholly improved habits where I find time to prepare and also now can pin down what I need to know. Before FIPSE I did not know how to study. Now, I have developed great study habits.

This program helped me see myself as a future engineer! I didn't do that before, but now I have higher expectations.

I am a re-entry student. I have found myself to be completely committed to studying and becoming an engineer

Yes! my commitment to my major changed as a result of my participation in math/physics program. I saw the need of doing something, because I like it, not because it is a hard career.

My dedication, actually my curiosity, my knowledge are some of the things I discovered more deeply through this program. I have more confidence that I can do it.

Visiting engineering firms and colleges was very inspirational and made it seem more possible that I could actually make it. Engineering is my dream but I'm not sure I'll get a job, but this class has given me a lot of confidence.

As far as the combining of the math and physics these are some of the comments:

Helped in the understanding of especially tricky stuff. The combining of the classes made the biggest difference when concepts were interrelated.

I find it extremely helpful to get the view from each perspective. I especially appreciate when the instructors participate jointly in the lectures.

The math/physics program is exceptional. The two classes work well together and help you understand both sides and how both fields work together.

It's helpful knowing there is practical application for all these math equations. I don't like having to memorize formulas that have no meaning. Math becomes a tool, a means to an end, rather than an arduous task of manipulating weird symbols.

The only way to go. . .It is critical to be able to make the connection between the two.

This combination- a mathematician and a physicist in a classroom should be retained.

I believe that every engineering student should take physics and math in this manner.

Very powerful. I never thought they had so much to do with each other.

When both teachers were in the room . . . the explanations and information were clear and interesting.